Λ(1520) production in proton-proton and proton-nucleus collisions with HADES

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Hyperon program @ HADES

Strangeness production in πp/pp, pA and HI collisions up to AuAu is a significant part of HADES Physics Program (see, talk by M. Lorentz).

- Inclusive Λ(1116) production, polarization and p-Λ correlations in pp/pNb

  Phys.Rev.C 95 (2017) 1, 015207, Eur.Phys.J. A50 (2014) 81, Phys.Rev.C 94 (2016) 2, 025201

- Inclusive Λ(1116) and Σ^0 production in pNb@3.5 GeV

  Phys.Lett. B781 (2018) 735-740

- Exclusive $\Sigma(1385)^+$ production in pp@3.5 GeV

  Phys.Rev. C85 (2012) 035203

- Exclusive Λ(1405) production and line shape measurement in pp

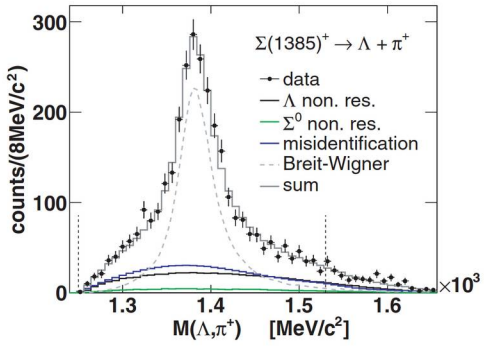
  Phys.Rev. C87 (2013) 025201

- A Ξ production in pA

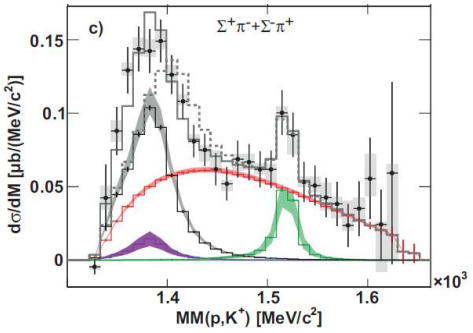
  Phys.Rev.Lett. 114 (2015) 212301, Phys. Rev. Lett.103, 132301 (2009)

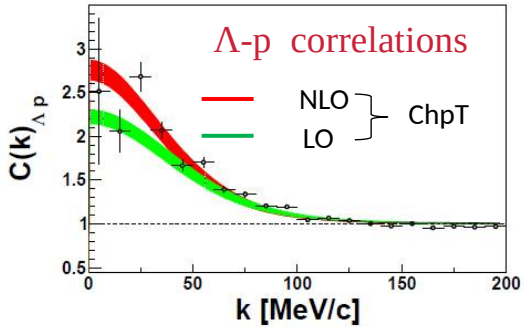
The program will be continued with new experiment pp@4.5 GeV (2022)

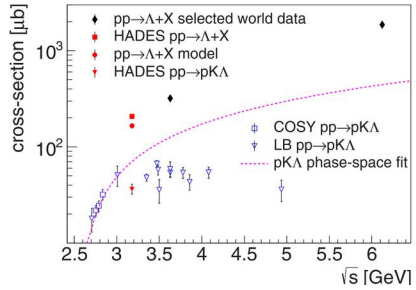
Σ(1385)



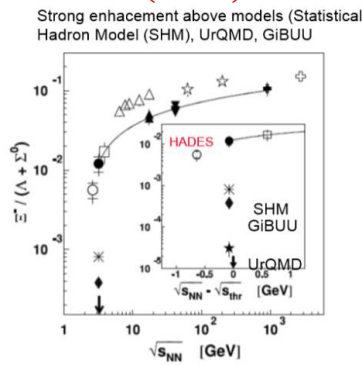
Λ(1405)







Ξ(1321)



Hyperon radiative & Dalitz decays

1) Sensitive probe of photon-baryon coupling (see talk by W. Przygoda, on HADES data for non-strange baryons)

a) Does Vector Meson Dominance works for baryon transitions?

b) What is a role of pion cloud (see talk of G. Ramahlo)?

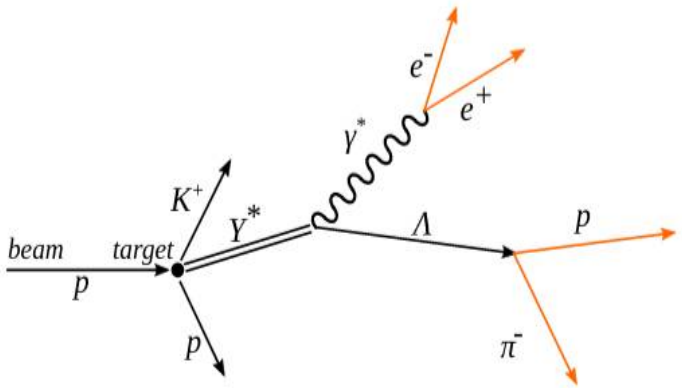
2) Radiative decays widths (keV) are sensitive to internal structure

$B_i \to B_f + \gamma$	χQM	NRQM	RCQM [5]	BonnCQM [6]	MIT Bag [3]	Chiral Bag [7]
$\Lambda_{1405} \to \Lambda_{1116} + \gamma$	168	200 [3], 143 [4]	118	912	60, 17	75
$\Lambda_{1405} \to \Sigma^0_{1193} + \gamma$	103	72 [3], 91 [4]	46	233	18, 2.7	1.9
$\Lambda_{1520} \to \Lambda_{1116} + \gamma$	134	156 [3], 96 [4]	215	258	46	32
$\Sigma^{*,0} \to \Lambda + \gamma$	234	273 [3], 232 [4]	267		152	

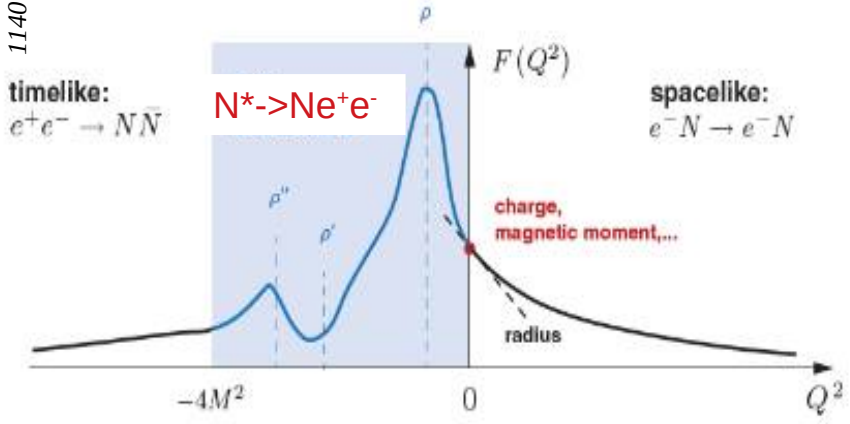
2) Hyperon transitions : i.e $\Lambda(1520)/\Sigma(1385) \to \Lambda(1116)e^+e^-$ are ideal probes to measure FF in time-like region (states are narrow !)

BUT BR are low $\Lambda(1520) \to \Lambda(1116)\ e^+e^- = 3.9 \cdot 10^{-5}$

AND cross sections for production in pp ARE NOT KNOWN at E ~ few GeV region (HADES)



PHYSICAL REVIEW D73, 114001 (2006)



Hyperons in nuclear medium: Λ(1520) case

pp Nuclear matter

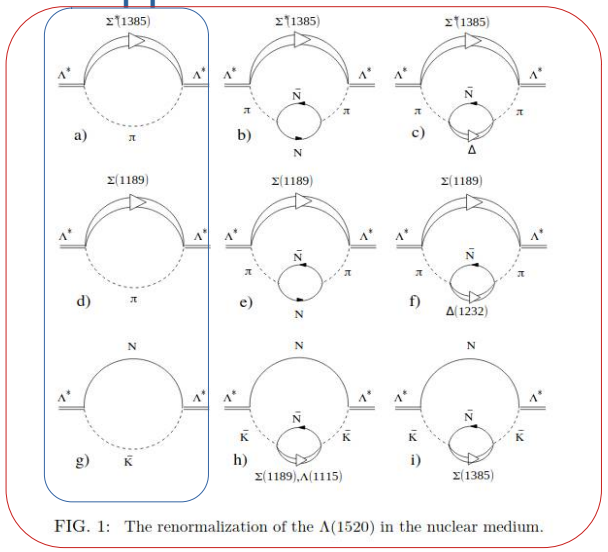


FIG. 1: The renormalization of the Λ(1520) in the nuclear medium.

"Λ(1520)and Σ(1385)in the nuclear medium" Murat M. Kaskulov and E. Oset

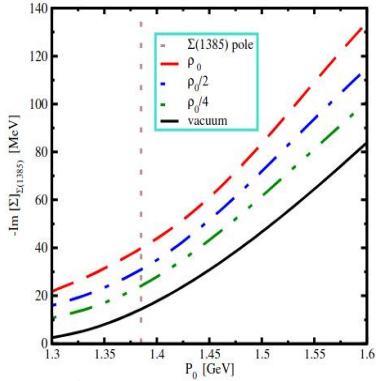
Λ(1520) structure is controversially discussed:

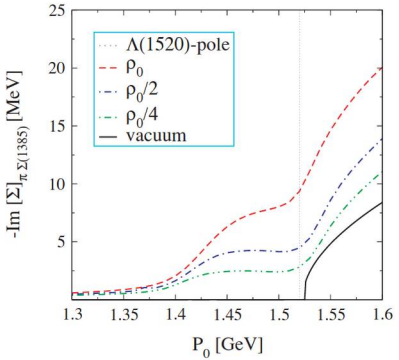
- Excited quark state (see previous slide)
- Baryon – meson molecule : Λ(1520)" is a dynamically generated state resulting from decouplet baryon x meson interaction (*S.Sarkar, E. Oset, J. Vacas "Baryonic resonances from baryon decuplet-meson octet interaction"*)

Important implication for in-medium properties of : Λ(1520)

Modification of $\Sigma(1385)^-$ π loop

- M↓(1500-1490 MeV)
- Γ↑(40-70 MeV)
- BR(Λ ππ) ↑(~25%)
- Changes for Σ*(1385) even stronger





Decay $\Lambda(1520) \rightarrow \Lambda(1116)\pi^-\pi^+$ in pp and pA

- Never measured before in pp and pA reactions! Only one measurement of this decay branch in K^-p experiment (Terry S. Mast, Margaret Alston-Garnjost et. al. Phys. Rev. D 7 1973)
- Complementary channel to $\Lambda(1520) \rightarrow \Lambda(1116)e^-e^+$
- Compare to Dalitz, high BR = $6.6 \cdot 10^{-2}$

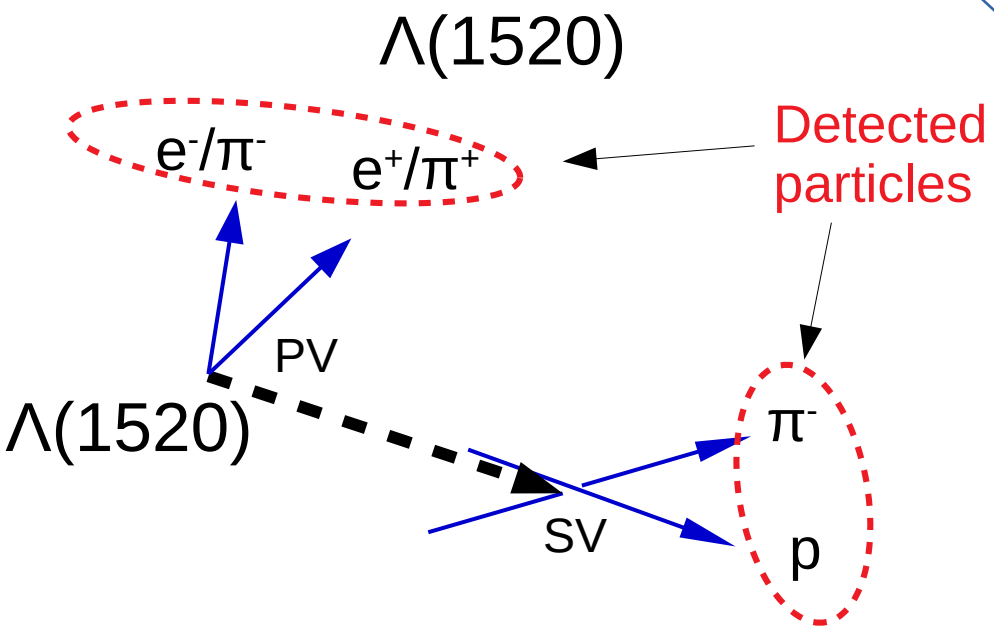
Λ(1520) identification in pp and pA

Dominant production channel

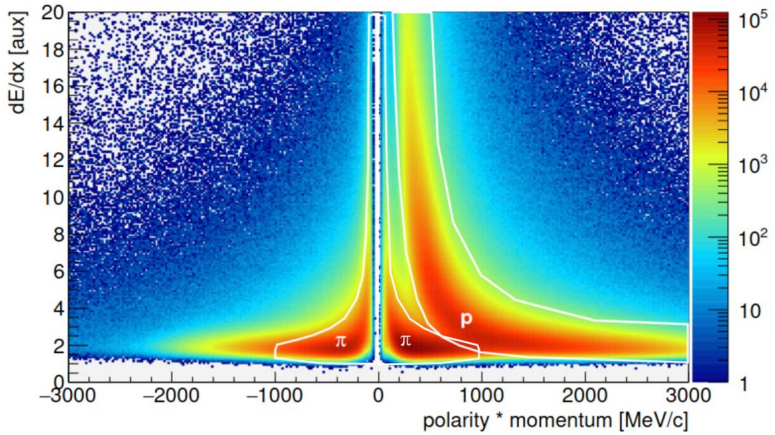
$pp \rightarrow pK^+\Lambda(1520) \rightarrow pK^+\Lambda(1116)\pi^+\pi^-$

Reference channel (known cross-section)

$pp \rightarrow p\pi^+K^0\Lambda(1116)$



	pp@3.5 GeV	pNb@3.5 GeV
1	p/π+/π- identification by de/dx	
2	$M^{miss}_{p\pi^-\pi^+\pi^-} > M^{inv}_{p\,K^+}$ for Λ(1520) $M^{miss}_{p\pi^-\pi^+\pi^-} > M^{inv}_{p\pi^+}$ for $\Lambda(1116)K^0$	No cut
3	$M_{p\pi^+} < 1200$ MeV/c^2	
4	Λ(1116) reconstruction with neural networks	
5	$M_{\pi^+\pi^-} < 420$MeV (K^0 suppression)	
6	Λ(1520) reconstruction, PV-SV>cut	



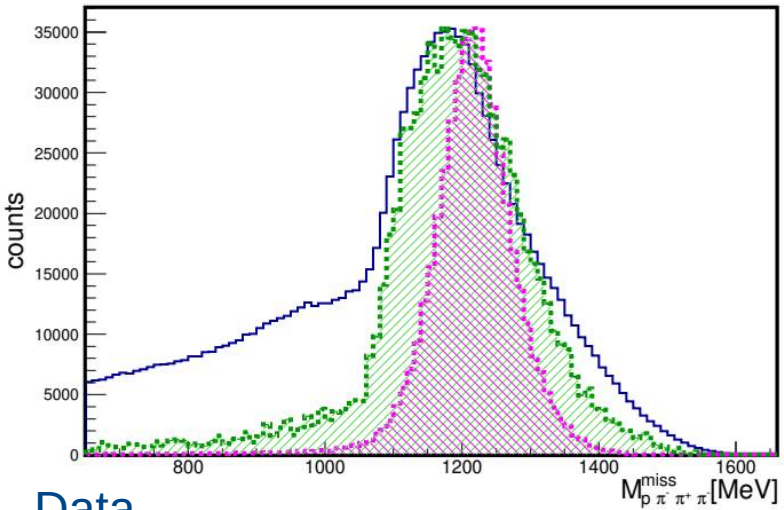
Missing mass cut

signal: $pp \rightarrow p K^+ \Lambda(1520) \rightarrow p K^+ \pi^- \pi^+ p \pi^-$

dominating background: $pp \rightarrow p \pi^+ \pi^- \pi^+ p \pi^-$

detected particles

missing mass

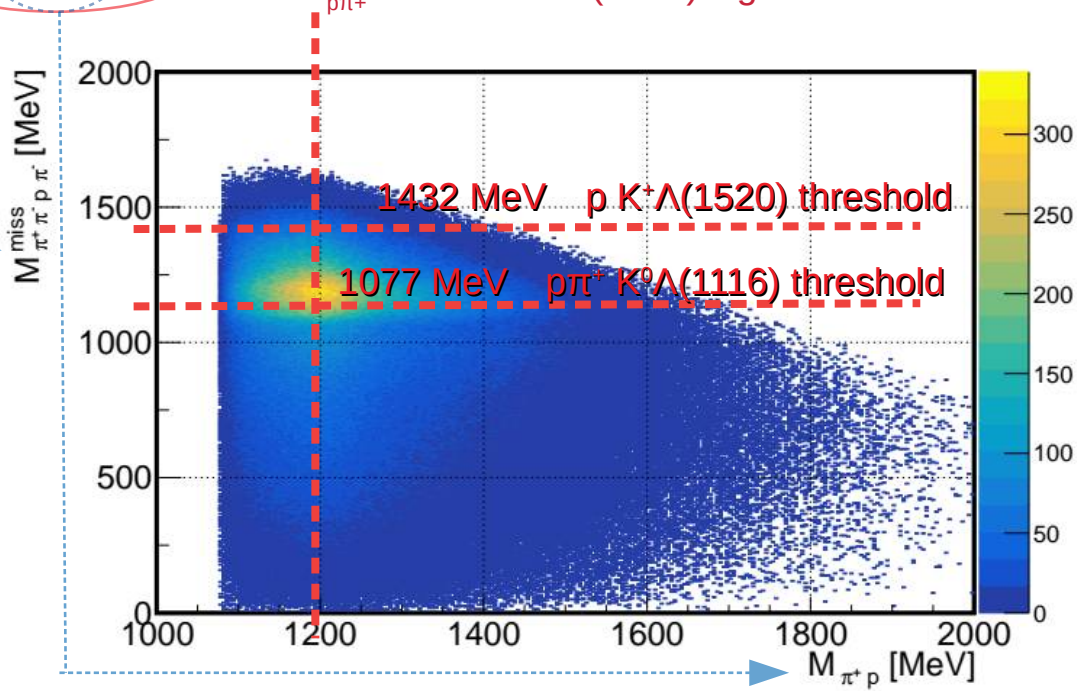


-Data

-pπ⁺ from Δ⁺⁺ decay

-any pπ⁺

$M_{p\pi+}$>1200 – no Λ(1520) signal reduction



Indication for main background channel

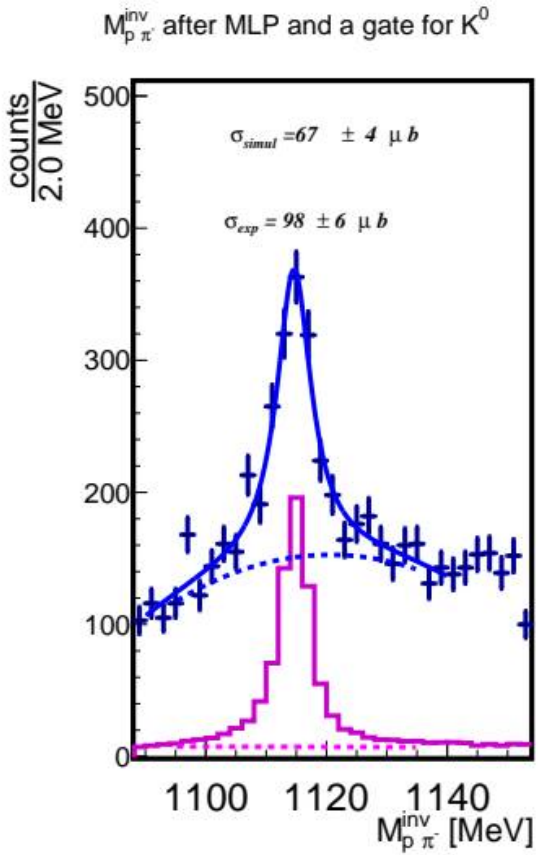
$pp \rightarrow N^{*+} N^{*+} \rightarrow \Delta^{++}\Delta^{++} \pi^-\pi^-$

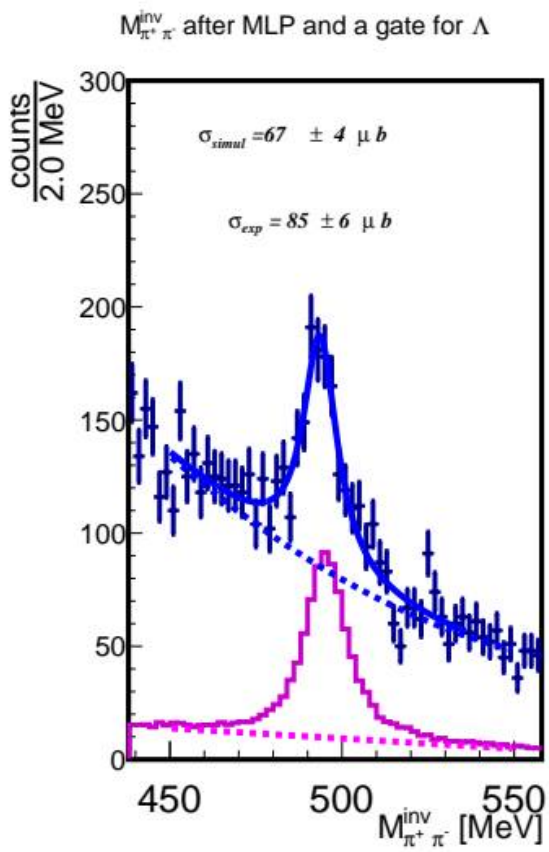
Reference channel: $\Lambda(1116)K^0$

- Simulation – sum of exclusive channels measured by HADES
  (*Phys.Rev. C95 (2017), 015207)*

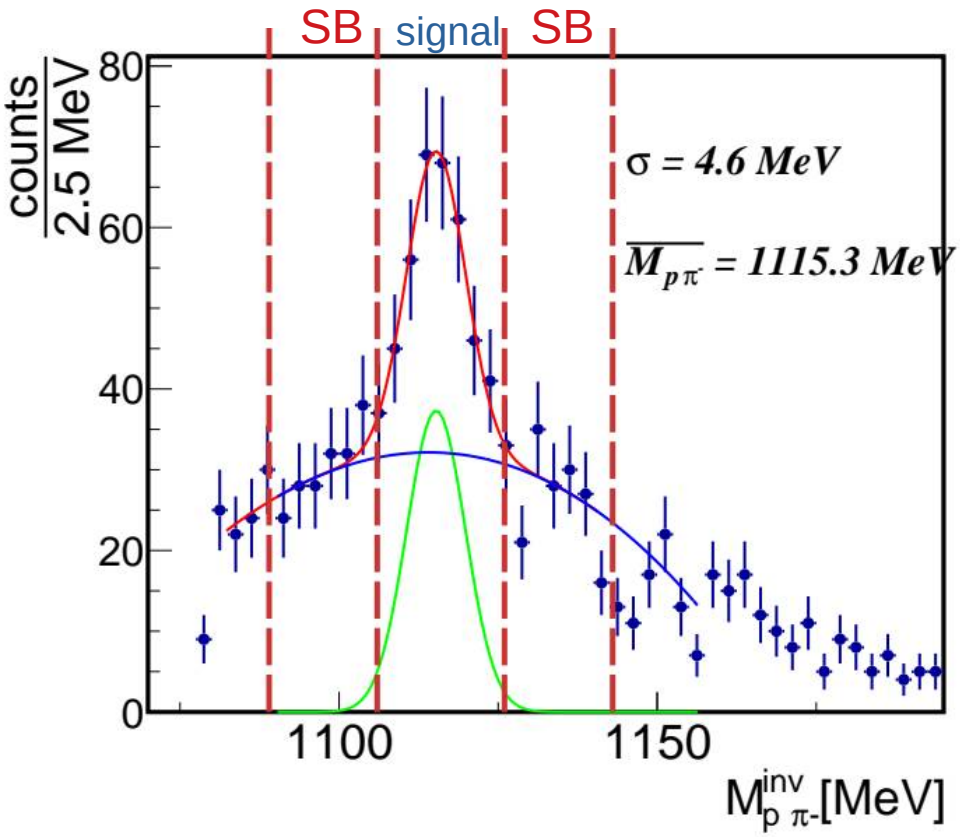
$\Lambda\Delta^{++}K^0$	$29.45 \pm 0.08\ ^{+1.67}_{-1.46} \pm 2.06$
$\Sigma^0\Delta^{++}K^0$	$9.26 \pm 0.05\ ^{+1.41}_{-0.31} \pm 0.65$
$\Sigma(1385)^+pK^0$	$14.05 \pm 0.05\ ^{+1.79}_{-2.14} \pm 1.00$
$\Delta^{++}\Lambda(1405)K^0$	$5.0 \pm 20\,\%$
$\Delta^{++}\Sigma(1385)^0K^0$	$3.5 \pm 20\,\%$
$\Delta^+\Sigma(1385)^+K^0$	$2.3 \pm 20\,\%$
$\Lambda p\pi^+K^0$	$2.57 \pm 0.02\ ^{+0.21}_{-1.98} \pm 0.18$
$\Sigma^0 p\pi^+K^0$	$1.35 \pm 0.02\ ^{+0.10}_{-1.35} \pm 0.09$
Sum	67,48 µb

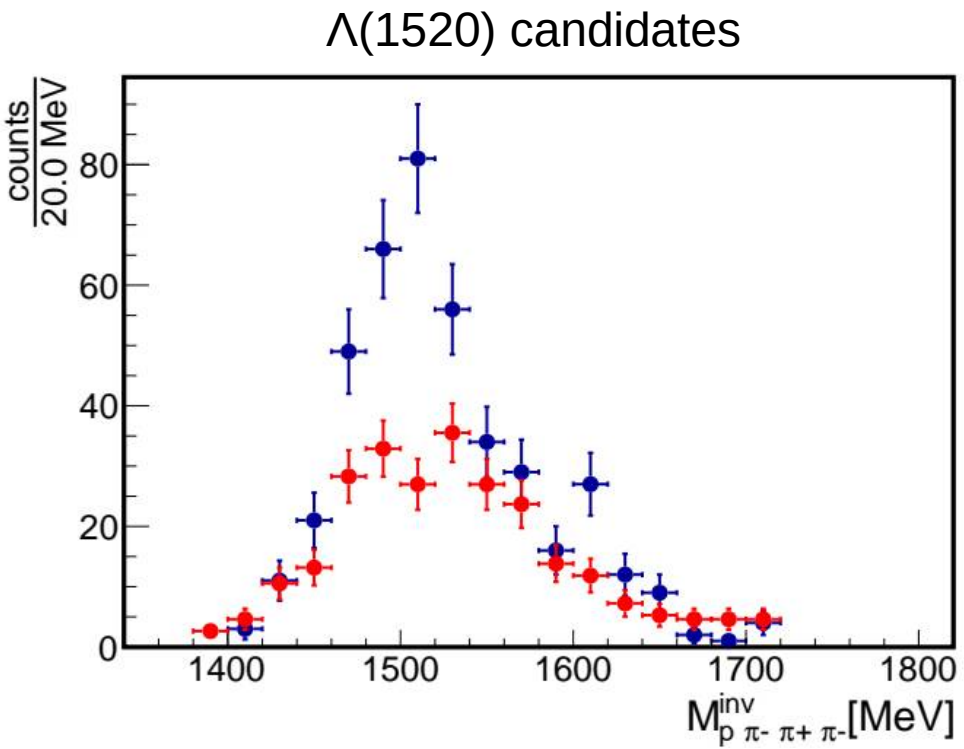
- simulated as $pp \rightarrow \Lambda^0K^0p\pi^+$
- Reasonable agreement (some exclusive channels missing)





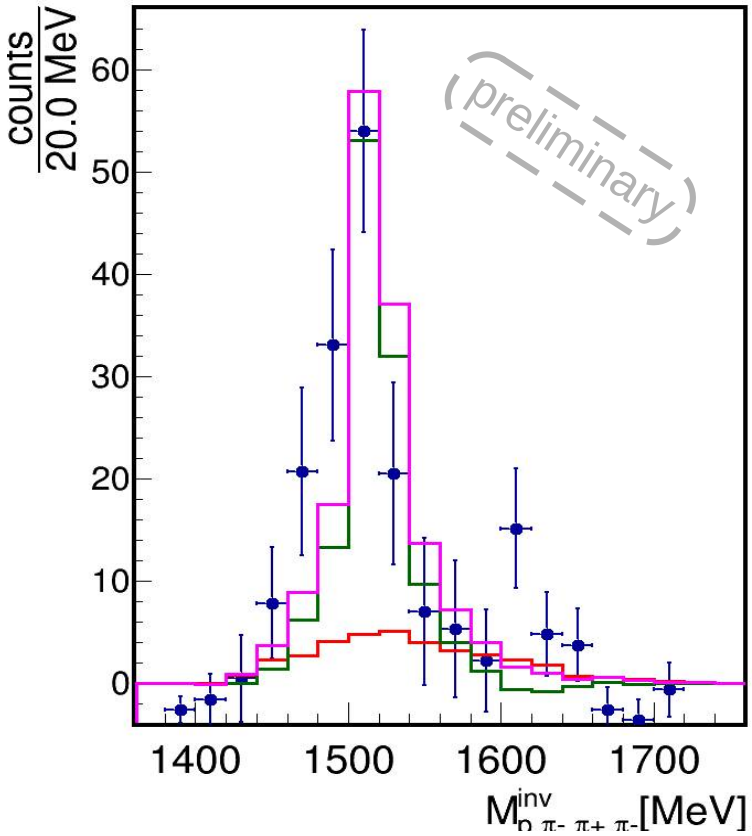
Λ(1520) candidates in pp@3.5GeV





- Data from L(1116) signal region
- Data from SB region

Λ(1520) signal in pp@3.5 GeV



$\sigma_{exp} = 6.2 \pm 1.1_{stat}\,\mu b$

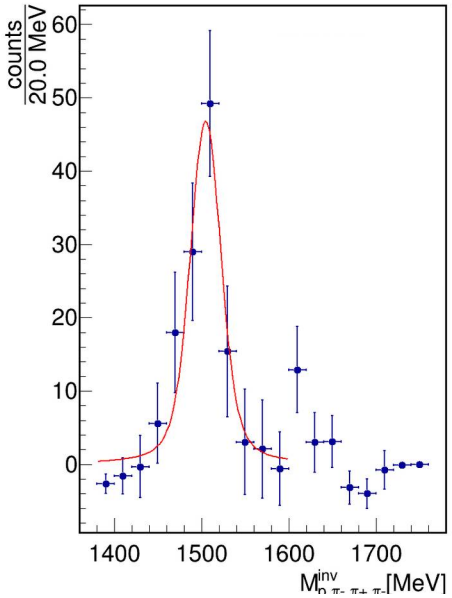
Signal and dominant non-resonant background channels tagged by Λ

$pp \rightarrow pK^+\Lambda(1520)$	6.2±1.1 μb
$pp \rightarrow \Delta^{++}K^0\Lambda(1116)$	29.45±2.06 μb
$pp \rightarrow pK^0\Sigma^+(1385)$	14.05±2.25 μb
$pp \rightarrow \Delta^{++}K^0\Sigma^0(1192)$	9.26±1.47 μb

Phys.Rev. C95 (2017) 015207

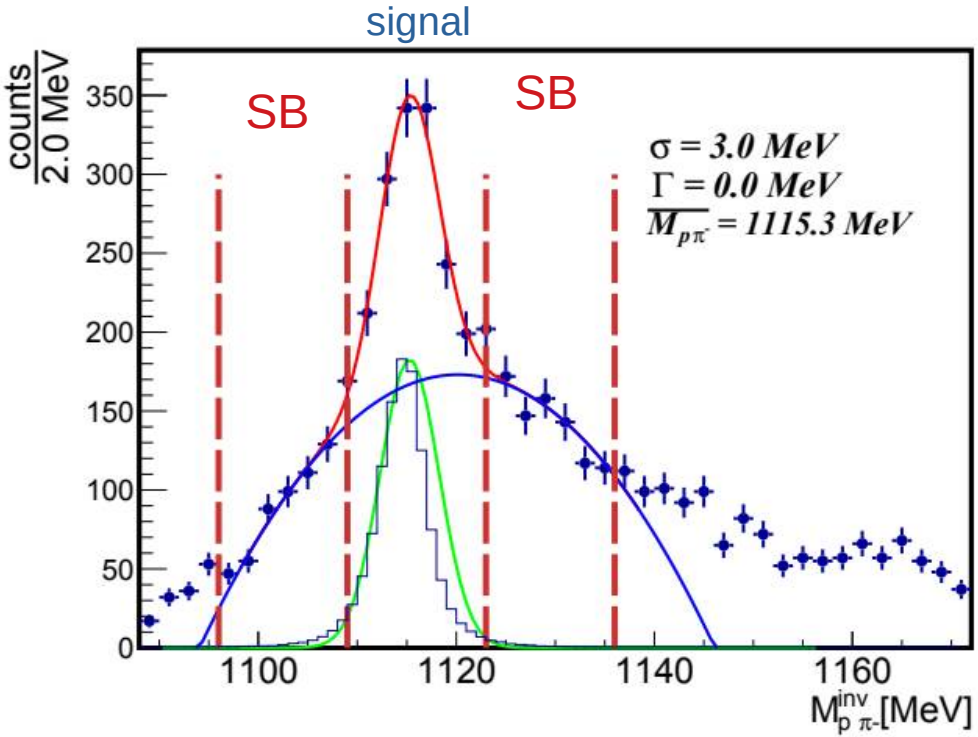
- data
– simulated signal
– simulated background
(from *Phys.Rev. C95 (2017) 015207*)
- simulated signal + background

After SB and background subtraction

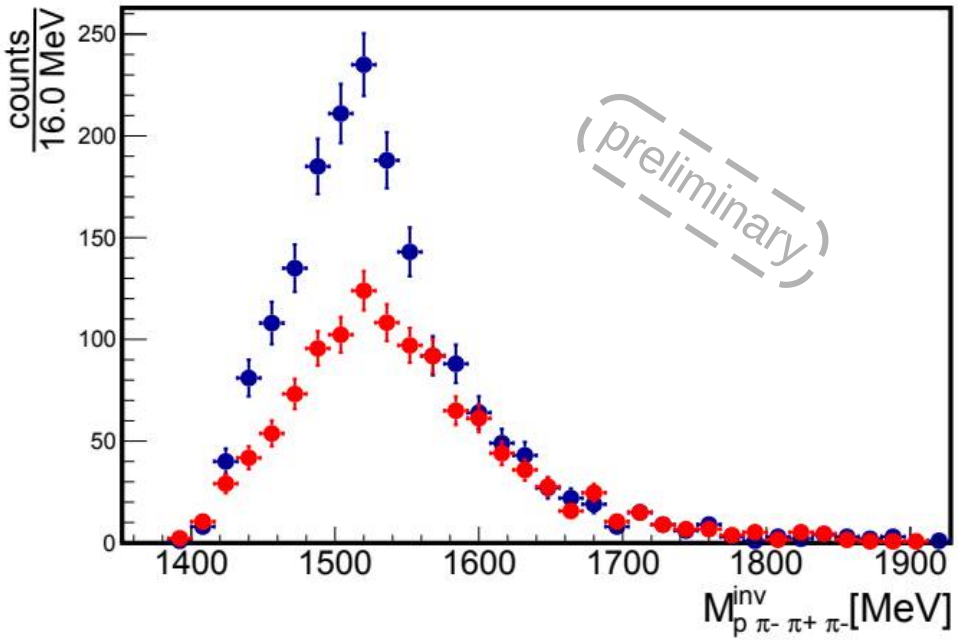


$M^{\Lambda 1520}_{exp} = 1504.5 \pm 4.5\,MeV$
$\Gamma = 15.6\,MeV\,(\mathrm{PDG})$
$\sigma = 14.0 \pm 6.6\,MeV\,(\mathrm{res.})$

Λ(1520) candidates in pNb: same cuts except missing mass



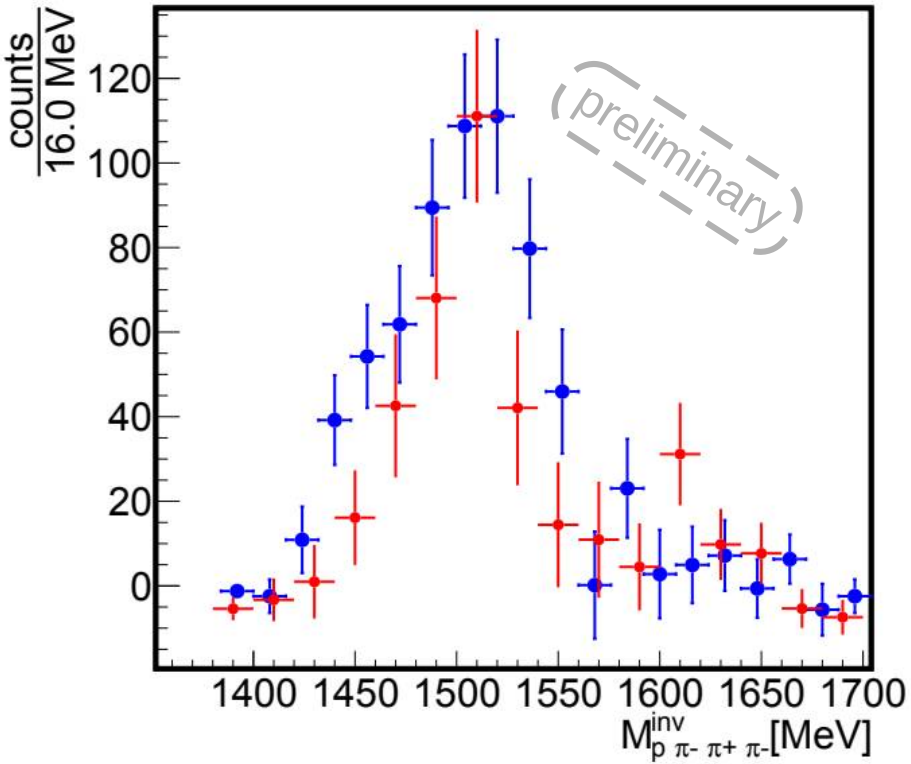
Λ(1520) candidates

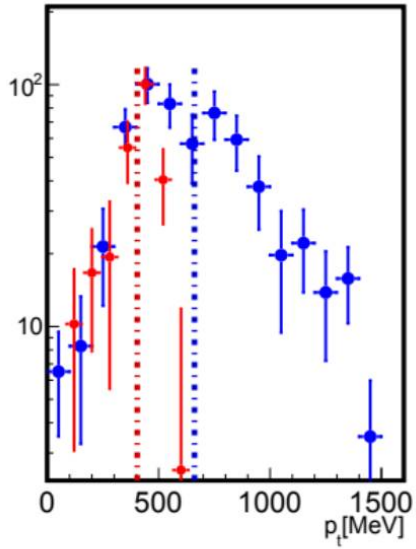


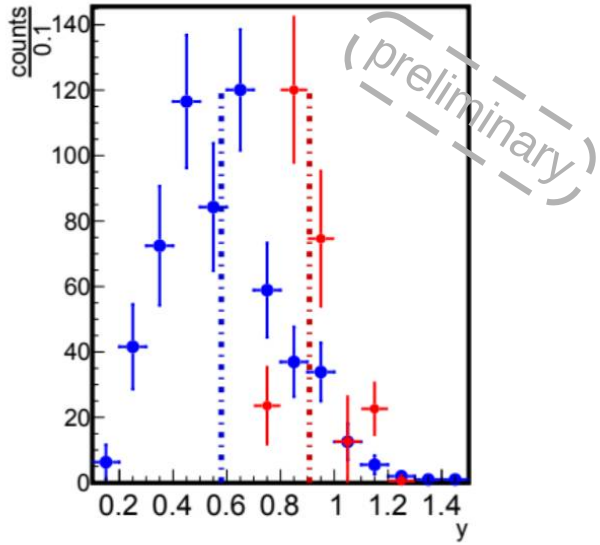
- Data from Λ(1116) signal region
- Data from SB region

Comparison with pNb@3.5 GeV data

Normalized to the same max value







- data from pNb
- data from pp, scaled up for comparison
- Mean values for pNb distributions
- Mean values for pp distributions

In P_t: pp lower by ~200 MeV/c

In y: pNb lower by ~0.3

Outlook → projections for upcoming experiment

Feasibility studies for Hyperon Dalitz decays in pp@4.5 GeV

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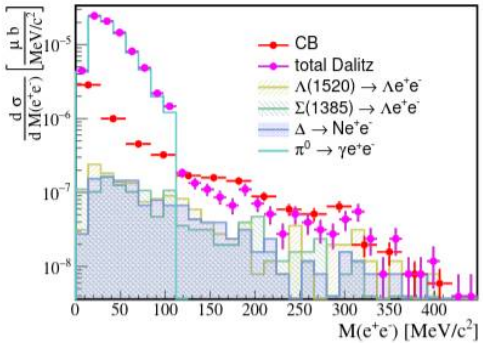
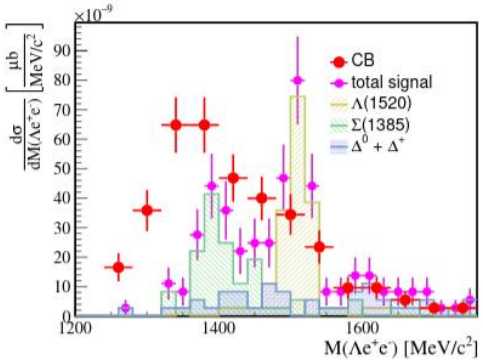
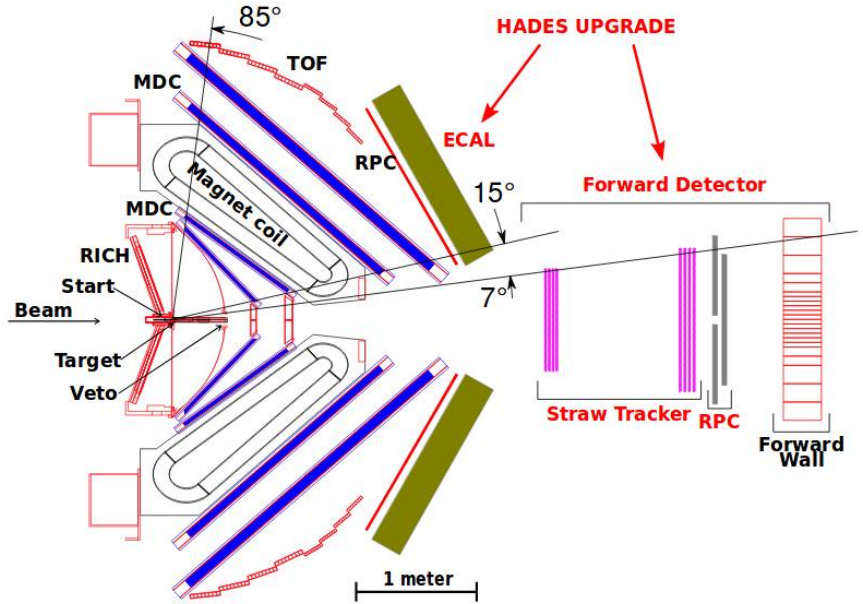


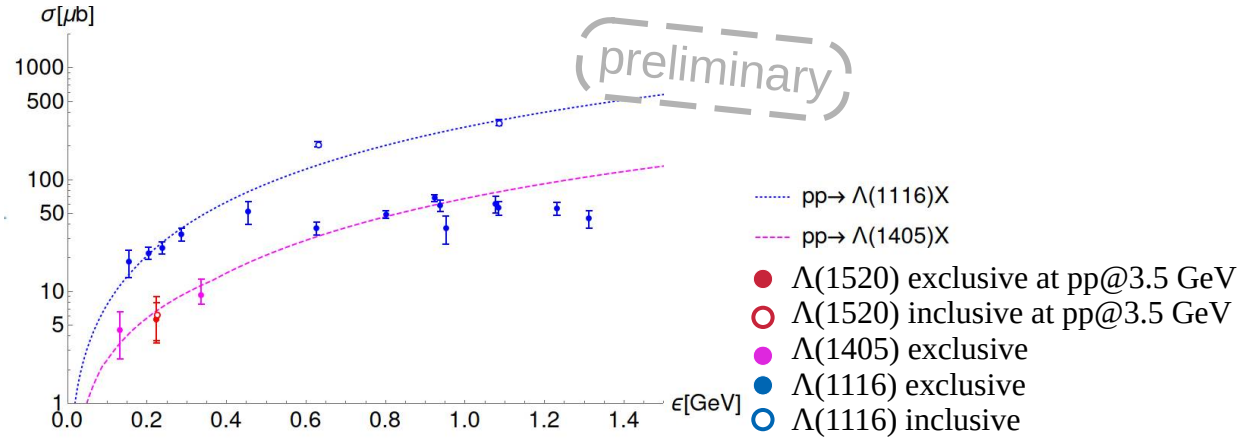


decay process	σ[μb]	counts/day (LH_2)	counts/day (CH_4)
$\Sigma(1385)^0 \to \Lambda e^+ e^-$	56	15	105
$\Lambda(1520) \to \Lambda e^+ e^-$	69	18	126
$\Lambda(1520) \to \Lambda \pi^- \pi^+$	69	2.64×10^4	1.85×10^5
$\Sigma(1385)^0 \to \Lambda \gamma$	56	99	692
$\Lambda(1520) \to \Lambda \gamma$	69	82	574
$\Xi^- \to p\pi^- \pi^-$	3.6	2.43×10^4	1.70×10^5
$\Xi^- \to p\pi^- \pi^-$	0.35	2.43×10^3	1.70×10^4
$pp \to \Lambda\Lambda K^+ K^+$	3.6	3.15×10^3	2.20×10^4
$pp \to \Lambda\Lambda K^+ K^+$	0.35	3.15×10^2	2.20×10^3



- Large statistics expected for hadronic and radiative decay channels for Λ(1520) and Σ(1385)
- First measurement of Λ(1520) and Σ(1385) Dalitz decays is feasible
- FwDet improves the HADES acceptance at forward angles – crucial for hyperons studies
- All upgrades already commissioned and tested
- The FwDet improve an acceptance for forward angles – crucial for hyperons studies

Summary



- Λ(1520) signal reconstructed in pp and pNb data
- Inclusive Λ(1520) production measured in pp, via $\Lambda(1520) \rightarrow \Lambda(1116)\pi^+\pi^-$, with $\sigma = 6.2 \pm 1.1$ μb
- Λ(1520) signal in pNb slightly broader than in pp (In-medium modification?)
- Significant shift for p_t and rapidity distributions between pp and pNb for Λ(1520)
- No significant shift in peak position for pp and pNb data
- Hyperon program will be continued, experiment planned for 2022

Thank you for your attention!
Dziękuję za uwagę!